THE ALSEA WATERSHED STUDY: Effects of Logging on the Aquatic Resources of Three Headwater Streams of the Alsea River, Oregon Part III - Discussion and Recommendations

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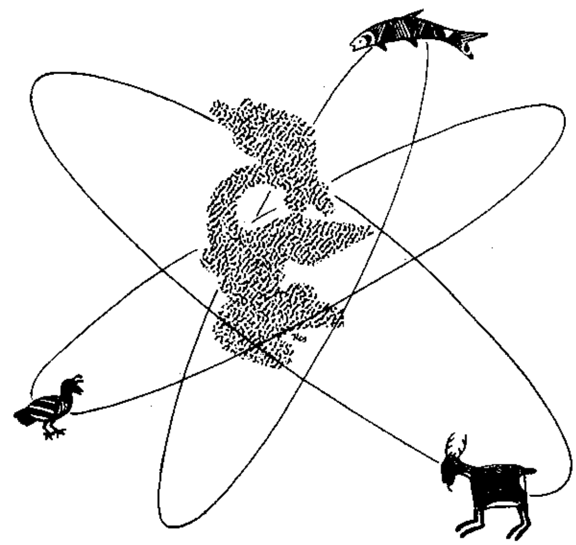

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TABLE OF CONTENTS

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ABSTRACT

On the basis of the results of the Alsea Watershed Study, detailed in Parts I and II and outlined herein, recommendations are offered for logging operations in areas with small headwater streams. The use of buffer strips is supported, along with the careful design, construction, and maintenance of logging roads. Felling of timber should be away from the stream. No yarding of logs ought to take place in or across the stream. Logging debris must be removed from the stream as soon after cutting as possible, but some debris can remain in the stream. State fisheries agencies should have input into proposed cutting plans.

INTRODUCTION

The small coastal streams of western Oregon are important spawning and rearing areas for several species of salmon and trout. Of the two important salmon species in Oregon (chinook and coho), coho salmon are characteristically present in these smaller streams. They share the stream habitat with cutthroat trout, rainbow and rainbow steelhead trout, as well as some nonsalmonid fish species. These small headwater streams are often located in timbered areas suitable for logging and associated road construction. Because of their small size and isolated location, they are often not given effective protection during felling and yarding operations.

Logging practices can indirectly result in changes in the biological components of a stream, and can have direct and indirect effects on the physical environment in streams. Felling trees into streams, or yarding timber across streambeds do not in themselves directly kill or redistribute fishes. But, changes in environmental parameters can and do influence the biological segment of the stream ecosystem. The primary environmental changes of concern are the effects of siltation, logging debris, gravel scouring, destruction of developing embryos and alevins, blockage of streamflow, decrease in surface and intragravel dissolved oxygen, increase in maximum and diel water temperatures, changes in pool/riffle ratios and cover, redistribution of fishes, reduction in fish numbers, and reduction in total biomass. The relationship of logging activities to these undesirable changes in stream environments has been explored in numerous logging studies in the western continental United States, Alaska, British Columbia, and elsewhere.

whew!

In earlier years, logging studies were characteristically short-term and concerned with obvious stream damage related to logging activities. Although short-term studies continue to be undertaken, they are much more detailed and involved with pertinent problems. When sufficient funds are available, researchers are turning to long-term case history studies, where definitive results can be obtained.

The principal logging study in Montana was the long-term Pinkham Creek project in the Stillwater River Drainage. The studies involved, primarily, the yearly monitoring of trout and char population numbers (Stefanich 1957; Hanzel 1961). Several studies in Idaho have concentrated on the effects of logging on salmonid streams. Bachman (1958) measured physical and biological conditions in trout streams of three uncut watersheds and one logged watershed in Idaho. Water temperatures apparently did not change following logging, but sedimentation from road construction did increase, especially during periods of heavy runoff. Edgington (1969) reviewed the findings of an 11-year study of two trout streams. The stream in one watershed (where 8 percent of the area was logged) exhibited no significant change in water quality or level of bottom invertebrates. On the other stream, however, 97 percent of the basin was cut, and several changes were noted. Siltation was evident in the early years as a result of road construction, and the abundance of four orders of insects declined for several years, then recovered by the end of the study. The U.S. Forest Service has studied sediment levels, gravel composition and salmon populations on the South Fork of the Salmon River (Platts 1974a, 1974b, 1974c). Sediment levels increased on the stream from

1952-1965 as a result of logging and road construction. Since 1966, the river system has been able to expell much of the excess sediment. Although the available spawning gravel appears to be increasing in known spawning grounds, it is doubtful the sediment loads in the river will ever return to the pre-logging conditions.

Washington logging studies have been limited. Wendler and Deschamps (1955) described the blockage of salmon runs by splash, roll and pond-type log dams. Deschamps (1971), Cederholm and Lestelle (1974) and Fiksdal (1974) studied the effects of logging on Stequaleho Creek and the Clearwater River. Generally, the concern was several landslides into the river, resulting in siltation increases. Cederholm and Lestelle studied salmonid populations during 1971-72, along with gravel composition, suspended sediment, and benthic invertebrates. Levels of fines increased in the spawning bed gravel of the streams, but the hatching survival of cutthroat trout embryos was not significantly changed in these areas from hatching survival in unaffected sections. Coho salmon population densities were low, and the levels of benthic invertebrates were significantly lower than in unaffected areas of Stequaleho Creek.

The California Department of Fish and Game has been involved in logging damage surveys and localized surveys for many years (Cordone and Pennoyer 1960; Fisk et al. 1966), but this type of activity has given way to the long-term case history type of study. One of the enduring logging studies in the west has been the cooperative Caspar Creek study in northern California (Kabel and German 1967; Burns 1972). From its inception in 1960, researchers at Caspar Creek, and other northern California streams, continually monitored streamflow. Other factors measured for shorter periods have included biological aspects (Burns 1971), and environmental changes (Burns 1970; Kopperdahl et al. 1971; Krammes and Burns 1973). Researchers have found that sediment levels increased during and after road construction. During the first winter following road construction, sediment levels were over four times higher than pre-construction levels, but have decreased in subsequent years (Krammes and Burns). Water temperatures increased slightly following road construction (Krammes and Burns), but temperature increases were greater following logging (Kopperdahl et al.). Burns (1972) indicated salmonid populations were altered as a result of logging and road construction.

British Columbia logging research has been applied to several logging related problems. The Canada Department of Fisheries and other agencies (Anonymous 1966) analyzed the problem of log driving on salmonid populations and their environment in the Stellako River. Results indicated log driving causes gravel scouring and disruption of spawning beds, erosion of river banks, a greatly reduced recreational fishery along the river, and increased levels of bark and debris in the stream and in the spawning gravel. Additional studies by Servizi et al. (1970) have shown that decaying bark may have a significant effect on developing sockeye salmon eggs. Short-term logging studies on Jump Creek and Wolf Creek, Vancouver Island, indicate some changes in fish populations in logged streams (Narver 1972), while the ongoing Carnation Creek study hopes to answer several questions with the case history approach (Narver 1971).

The harvest of timber in Alaska has increased significantly in the past 30 years. Initial logging research by the U.S. Forest Service began in 1949, and has continued at various levels to date in southeast Alaska (Sheridan and McNeil 1968; Meehan et al. 1969; Sheridan and Olson 1970). Beginning in 1956, the Fisheries Research Institute of the University of Washington has supplemented the federal research in several stages. The major emphasis in the 1950's and 1960's was on the pink and chum salmon streams of southeast Alaska (Salo 1967). More recent logging studies have concentrated on coho salmon and associated changes in environmental conditions (Tyler and Gibbons 1973), and the effects of log rafting on the marine benthos (Pease 1974). In the last several years, the National Marine Fisheries Service has conducted research into log rafting problems (Ellis 1973). The Alaska Department of Fish and Game has continued research into the effects of logging on Dolly Varden (Reed and Elliott 1972) and salmon (Kingsbury 1973), and the toxicity of decaying bark on pink salmon fry and some crustaceans (Buchanan et al. 1975). Out of the Dolly Varden study came a series of guidelines for logging operations and baseline biological measurements in important southeast Alaska sports fishing areas (Elliott and Reed 1973).

Several logging studies have been undertaken in the Cascade Range of Oregon, including the Steamboat Creek drainage area (Brown et al. 1971), and the H.J. Andrews Experimental Forest (Wustenberg 1954; Brown and Krygier 1967; Levno and Rothacher 1967, 1969). Brazier and Brown (1973) studied applications of buffer strips in both the Cascade Range and the Oregon Coast Range, and Moring and Lantz (1974) reported the findings of a six-year study of 12 coastal streams of western Oregon. Cutthroat trout populations appeared to decrease on streams following logging, but the reactions of coho salmon populations were mixed. Maximum stream temperatures increased, and dissolved oxygen levels generally declined after logging. There were also changes in amounts and composition of spawning gravel, but those streams with intact buffer strips suffered less damage than those without buffer strips.

buffers

The limitations of short-term studies, however detailed, become apparent when the lack of background data on biological and physical cycles hinders the interpretation of results. Most long-term case histories of logged watersheds have only been undertaken in the last 25 years. The results of the largest such study, the Alsea Watershed Study, will be reported here. The 15-year study was the most extensive study of biological and environmental features of logged and unlogged watersheds ever undertaken in North America.

The Governor's Committee on Natural Resources established the Alsea Watershed Study in 1957. Funding from this source disappeared a year later, but federal and state agencies supported the work for the 15-year study period. The Alsea

Watershed Study was a cooperative venture involving numerous individuals and agencies. Principal cooperators throughout the study were the Oregon State Game Commission (Oregon Department of Fish and Wildlife), Oregon State University (primarily the School of Forestry, and the Departments of Botany, Civil Engineering, Entomology, and Fisheries and Wildlife), the U.S. Forest Service, U.S. Geological Survey, Federal Water Pollution Control Administration, the Georgia-Pacific Corporation, and Mr. Fred Williamson, a private landowner. Other cooperators included the U.S. Public Health Service, Oregon Cooperative Wildlife Research Unit, Oregon State Board of Forestry, and the Department of Environmental Quality. In addition to the Georgia-Pacific Corporation, the logging companies were the Stokes Lumber Company and Timber Access Industries, both of Corvallis, Oregon.

Studies began in July 1959 on three small watersheds in Lincoln County, Oregon. The three creeks involved are headwater tributaries of the lower Alsea River. One watershed, Flynn Creek, was left unlogged, and served as a control. The Deer Creek watershed was patch cut with intact buffer strips along the stream. The Needle Branch watershed was clearcut without buffer strips.

Logging road construction took place during May to October 1965. The timber harvest on the Deer Creek and Needle Branch watersheds occurred the following year, again during May to October. Slash burning was completed on Needle Branch and on two sections of Deer Creek prior to November 1966. The remaining section was slash burned some months later. Post-logging studies continued until October 1973.

This sequence provided a 7-year pre-logging study period, 1959-1965, logging in 1966, and a 7-year post-logging study period 1967-1973. For comparative estimates, the period 1959-1965 constituted the pre-logging work and 1966-1973 constituted the post-logging work. Among the primary objectives of the work were:

1. To study in depth the population characteristics of salmonids and other fish species in Flynn Creek, Deer Creek and Needle Branch over a 15-year period, 1959-1973.

2. To study the direct and indirect effects of logging on fish.

3. To compare the effects of two common logging techniques on biological and physical properties of streams, using Needle Branch and Deer Creek as test streams, and Flynn Creek as a control stream.

4. To analyze the effects of environmental changes (natural and logging-related) on salmonid fish species, particularly coho salmon and cutthroat trout.

5. To derive some indication of the natural fluctuations in fish populations and physical and biological properties of the three Alsea Study streams.

6. To make recommendations, on the basis of accumulated data, as to desirable and undesirable logging practices (including road construction, buffer strips, and yarding and felling of trees).

In order to present the results of this extensive study in the most logical manner, three separate but related Alsea Watershed Study reports are being issued. Part I includes the results of the biological investigations of the study. Part II includes the results of the environmental measurements during the study. Part III includes the discussion, summary and recommendations. Numerous papers, theses and disserations have been issued on various aspects of the study during the past 15 years. Pertinent results of these publications, as they pertain to the results and discussion of accumulated data, will be included.

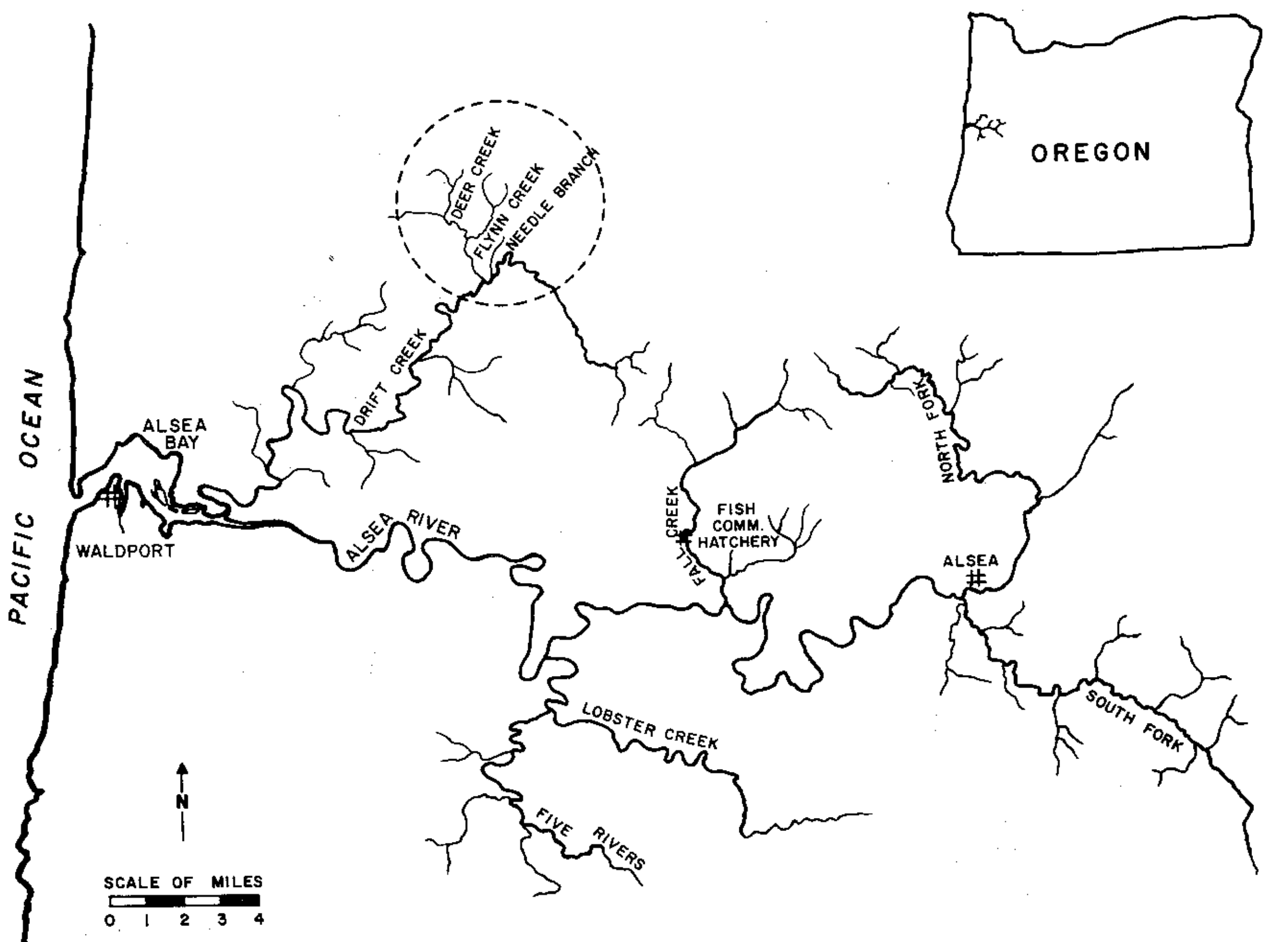
STUDY AREAS

Three headwater tributaries of the Alsea River were selected for study. The Deer Creek, Flynn Creek and Needle Branch watersheds are located in a portion of Lincoln County, approximately 16 km (10 miles) south of Toledo, Oregon (Figure 1). All three streams eventually flow into Drift Creek, and ultimately into Alsea Bay. Deer Creek is a tributary of Horse Creek. Flynn Creek is the major tributary of Meadow Creek, which then flows into Horse Creek. Horse Creek joins Drift Creek approximately 60 meters from the junction of Needle Branch and Drift Creek (Figure 2). Drift Creek flows southward until entering Alsea Bay approximately 6.4 km (4 miles) east of Waldport.

The three streams have extremely variable flow rates, and are of different sizes. Needle Branch is the smallest stream, followed by Flynn Creek, and then Deer Creek. The three creeks can be considered typical of small western Oregon headwater streams. The principal cause of the variable flow rates is the combined effect of the small sizes of the streams, and the effects of winter freshets, which generally occur from November to February.

The study area is located in the northern Oregon Coast range in a region of heavy rainfall. Mean annual precipitation was reported by Hall and Lantz (1969) as 244 cm (96.1 inches) during the 1959-1965 pre-logging period. Air temperatures ranged from approximately -7 to 32°C (19 to 90°F). Snowfall in the area is relatively light, occurring only two or three times per year, and never remaining on the ground for long periods.

The geology of the region is typical of the northern Oregon Coast range, with the principal underlying component the northern extension of the Tyee sandstone formation. Corliss and Dyrness (1965) have summarized the principal soil and vegetation components of the area, but particular vegetation characteristics of each watershed will be discussed in more detail in the descriptions of individual stream sites. Generally 100-year-old Douglas-fir (*Pseudotsuga menziesii*) was the principal commercial species harvested. The important hardwood in the area was red alder (*Alnus rubra*). Understory vegetation was primarily salmonberry (*Rubus spectabilis*), sword fern *(Polystichum munitum)*,



Alsea River system and Drift Creek study area.

FIGURE 1. Location of Alsea Watershed Study in western Oregon.

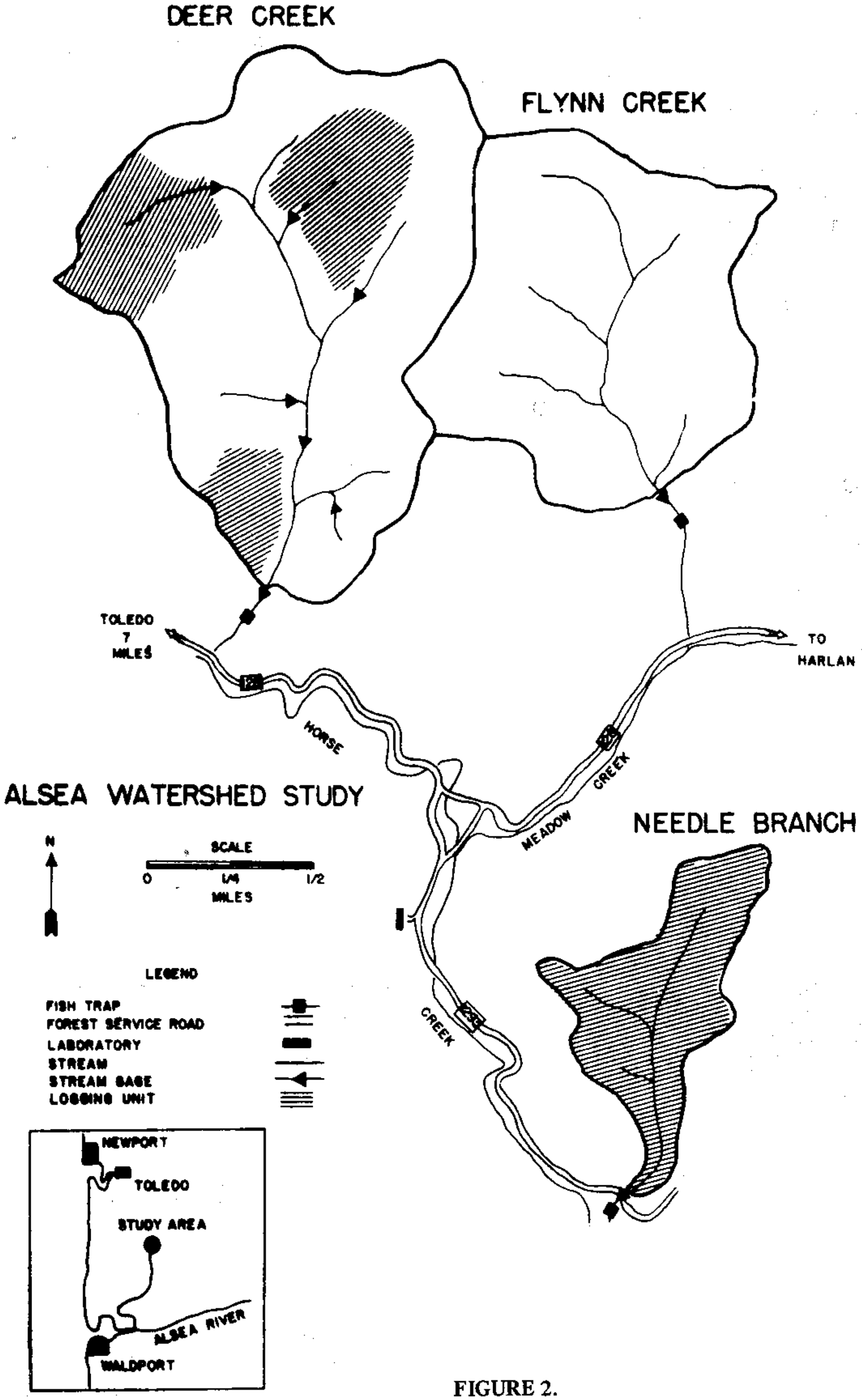


FIGURE 2.
Map of the study watersheds. The approximate lengths of the streams accessible to anadromous salmonids are: Deer Creek – 2324 m. Flynn Creek – 1433 m, Needle Branch – 966 m.

skunk cabbage (*Lysichitum americanum*) and vine maple (*Acer circinatum*).

Four salmonid species were present in one or more of the study streams: coastal cutthroat trout (*Salmo clarki clarki*), steelhead trout (*S. gairdneri gairdneri*), chinook salmon (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*). Steelhead trout and chinook salmon are uncommon and are usually only present in Deer Creek.

Chapman (1961, 1962, 1965), Au (1972) and Lindsay (1975) have described the life history patterns of coho salmon in the three study streams. Generally, adult coho salmon enter the streams to spawn from November through February and the fry emerge February through May. After a year of residence in the creeks, most juvenile coho migrate to sea the following spring. Lowry (1964, 1965,1966) has described the biology of cutthroat trout in the study streams. Sea-run adults follow similar migration timing as adult coho salmon, but juveniles may remain in the streams for several years prior to downstream migration. There is probably a resident population of cutthroat trout in the streams, but the sea-run component dominates. Distinguishing which juveniles or adults in streams may be "residents" is difficult, because some sea-run individuals may remain in the stream for as much as five years before migrating (Richard Giger, personal communication). Others may move to the estuary and no further, thus confusing scale analysis.

Other fish species in the streams were the reticulate sculpin (*Cottus perplexus*), Pacific lamprey (*Entosphenus tridentatus*), and western brook lamprey (*Lampetra richardsoni*). No other fish species were noted during the 1959-1973 study period.

Principal laboratory and housing facilities for the project were at the laboratory located along Horse Creek (Figure 2). Studies concerning gravel incubation, predation, and the effects of sedimentation, among others, were conducted at this station (see Methods sections in Parts I and II). The field location of the laboratory provided easy access to the biological and physical components of the study streams.

FLYNN CREEK

The Flynn Creek watershed (approximately 202 ha) was not logged, and served as a control for the study. Stream length is approximately 1,433 m, with mean summer width 1.74 m, and mean summer depth 13 cm (Chapman 1961). The stream gradient averages 0.025 m per stream meter.

Stream distance was marked by stakes from the gauging station (0 meters, 0 feet). The fish collection trap was located 305 meters (1,000 feet) downstream from the stream gauge. Between marker 305 meters (1,000 feet) and 549 meters (1,800 feet) there is a steep canyon which restricts the available stream area. Historically, there was little spawning in this steep area of much exposed bedrock. Following scouring in the winter flooding of 1971-72, the remaining gravel largely disappeared, and spawning activity in the canyon effectively ceased. There are four small tributaries to Flynn Creek (Figure 2), evenly spaced along the stream length. The final study marker stake was at 1,006 meters (3,300 feet) upstream. The portion of the stream beyond that point was unstudied.

During the pre-logging period, mean summer streamflow was 4.5 liters per second (0.16 cfs), and peak winter flow reached 3,877 liters per second (137.0 cfs) (Hall and Lantz 1969). Annual mean water temperature was 9.7°C, ranging from a minimum of 2.2 to a maximum of 16.6°C, essentially the same as those recorded on other streams in the pre-logging period. Diurnal temperature range varied from 0.5 to 2.2°C (Hall and Lantz).

The Flynn Creek watershed is owned by the U.S. Forest Service, and the principal species of trees are Douglas-fir and red alder. Douglas-fir were primarily 30 to 50 and 70 to 110-year-old stands. Alder stands were 30 to 70 years old. The understory species were salal (*Gaultheria shallon*), sword fern, vine maple and salmonberry. Isolated groups of bracken fern (*Pteridium aquilinum*) were also present.

DEER CREEK

The Deer Creek watershed is the largest of the three study areas, covering approximately 304 ha. The stream length is approximately 2,324 m, with an average summer width of 1.80 m, and an average summer depth of 11 cm (Chapman 1961). Stream gradient averages 0.018 meters per stream meter.

The fish trap was located 152 meters (500 feet) below the gauge station (or a stream location of -152 meters). A steep canyon is present from the 152 meter stream marker to approximately the 427 meter (1,400-foot) location. From 427 meters to 1,219 meters (4,000 feet), the stream is quite slow moving and meandering. The major tributary of Deer Creek was East Fork, entering at the 1,433 meter (4,700-foot) marker. Two smaller tributaries entered the main stream below the East Fork junction, and two smaller tributaries entered above East Fork. The final study marker stake was at 2,195 meters (7,200 feet) upstream from the gauge station.

Mean summer minimum streamflow in the pre-logging period was 8.5 liters per second (0.30 cfs). Peak winter flow was 5,688 liters per second (201 cfs). Annual mean water temperature in the pre-logging period was 9.6°C, ranging from a minimum of 1.1 to a maximum of 16.1°C. The diurnal range was 0.5 to 2.2°C (Hall and Lantz 1969).

Most of the watershed is owned by the U.S. Forest Service, with a small section near the mouth owned by the Georgia-Pacific Corporation, and the principal logged species of timber was Douglas-fir. Fir stands were primarily 50 to 70 and 70 to 110 years old. A few trees younger than 20 years were present in one small area. Red alder were primarily 40 to 60 years old. A few 20 to 40-year-old alder were present in the lower clearcut section. The understory was almost entirely salmonberry, vine maple and sword fern. Salal and bracken fern were present in a few isolated locations.

Locations of the three patches clearcut are shown in Figure 2. The lower section was along the west side of the stream at the effective lowest portion of the watershed. A buffer strip was left along the creek. The northern clearcut was on the hillside between the East Fork drainage and the main creek drainage. Buffer strips were left along all branches of the stream. The third area was at the extreme northwestern section of the watershed. Clearcutting occurred on both sides of the main branch in a section located immediately above the study area.

NEEDLE BRANCH

The Needle Branch watershed is the smallest of the study areas, only 75 ha in size. The stream length studied is approximately 966 m. The stream gradient is 0.014 meters per stream meter. Mean summer width is 1.10 m, and mean summer depth is 7 cm (Chapman). The fish trap was located approximately 61 meters (200 feet) below the stream gauge. The two distinctive features along the stream are small waterfalls at approximately 808 meters (2,650 feet) and 869 meters (2,850 feet). Two small tributary streams enter Needle Branch above the second falls. Beyond approximately 1,067 meters (3,500 feet), flow is greatly reduced, and isolated pools are present to the headwaters. The 792 meter (2,600-foot) marker was the final study area stake, but population estimates and other surveys were conducted above this point after 1966.

Mean summer minimum streamflow was 0.6 liters per second (0.02 cfs). The peak winter flow was 1,415 liters per second (50.0 cfs). The annual mean water temperature of 9.7°C before logging was similar to that on the other study streams. Water temperatures ranged from a minumum of 1.6 to a maximum of 16.1°C. The diurnal temperature range was 0.5 to 1.5°C prior to logging (Hall and Lantz 1969).

Part of the lower section of Needle Branch watershed was privately owned by Mr. Fred Williamson. The remainder was owned by Georgia-Pacific Corporation. Several timber species were present, including Douglas-fir, western red cedar (*Thuja plicata*), and red alder. Douglas-fir stands were all 70 to 110 years old, while cedar stands were 30 to 50 years old. A small stand of 30-50 year old Oregon white oak (*Quercus garryana*) was also present. The age of a small patch of alder was in excess of 100 years. The understory was primarily vine maple and sword fern, although salal, bracken fern, salmonberry, thimbleberry (*Rubus paraviflorus*) and dewberry (*R. vitifolius*) were also present. The vegetation of the lower and central portions of the watershed was similar to that on Deer and Flynn creeks, but the understory at the head of the stream consisted primarily of shrubs, herbs and various grasses.

The entire watershed was clearcut and later slash burned. No buffer strip was left along the streambed. No effort was made to protect the stream from logging activity, except to eventually clear debris from the channel.

DISCUSSION

THE WATERSHEDS DURING AND AFTER LOGGING

With the discussions in Parts I, II, and III of logging and its effects on aquatic life and habitat in the study streams, it is appropriate that the changes in Needle Branch and Deer Creek be shown pictorially. Road construction occurred in Deer Creek and Needle Branch from May to October 1965, but actual cutting did not begin until March 1966. The Georgia-Pacific Corporation, Stokes Lumber Company, and Timber Access Industries felled trees during late spring and early summer, 1966 (Figure 3, 4, 5, 6). Felling created considerable debris in Needle Branch (Figures 7, 8). Fish mortalities (coho salmon, cutthroat trout, reticulate sculpin) occurred in this period.

Debris was hand-cleared from Needle Branch in August 1966 (Figure 9), while the buffer strips left along Deer Creek protected the stream from most damage during the logging operation (Figure 10). The Needle Branch watershed and two units of the Deer Creek cutting were slash burned before November 1966 (Figure 11). The last Deer Creek unit was burned in the spring of 1967. Cutthroat trout and juvenile coho were killed during flash heating by slash fires in the canyon area (Figure 12).

In December and January 1967, there was a signficant increase in streamflow in Needle Branch over average flows for pre-logging years, and sedimentation increased during winter freshets (Figure 13). By the spring of 1967, Needle Branch was, visually, the most altered from pre-logging conditions (Figure 14, 15, 16).

In subsequent years, riparian vegetation (alder, salmonberry, vine maple) slowly returned to Needle Branch (Figure 17), helping to reduce the temperature extremes in summer months. Logging roads, however, continued to be a problem in post-logging years, particularly in Deer Creek (Figure 18). These road slumps and slides were a continuing source of sediment.

SYNOPSIS OF PRINCIPAL RESULTS

Changes in water temperatures

We have shown that water temperatures in Deer Creek were not significantly changed as a result of logging. The specific pre-logging temperature pattern was different in Flynn and Deer creeks, but the post-logging patterns were not altered from pre-logging conditions.

On Needle Branch, however, there was a pronounced change in water temperature maxima and ranges. Both aspects increased immediately after cutting, and increased further after debris clearance and slash burning, when solar radiation was maximized. Minimum temperatures remained essentially unchanged in post-logging years, but it took over 8 years after logging for temperature maxima and ranges to return to pre-logging values. The eventual return to normal values was due primarily to the return of noncommercial, riparian vegetation. This vegetative growth is more rapid in areas of the Coast Range than in the Oregon Cascades.

Water temperature increase was an important contributing feature in changes in other environmental and biological components of the stream. The increase in water temperature was partially responsible for the decrease in dissolved oxygen levels in the surface and intragravel environment. The rapid increase in water temperature during and after logging was probably the one factor most responsible for stressing and changing fish populations in Needle Branch. The fact that there was no such increase in temperature in the buffered Deer Creek system, and no such changes in dissolved oxygen and fish populations, lends credibility to this explanation that biological conditions were affected initially by changes in water temperature.

Lantz and Moring (1975 MS) have indicated a change in behavioral patterns of coho salmon and cutthroat trout in Needle Branch, as opposed to fish in a stream with nonelevated temperatures. Behavioral changes are a reflection of changes in environment and/or metabolism, and are important indicators of alterations in physical parameters. From a biological point of view, control of abnormal temperature changes would appear to be a principal concern in any regulations dealing with timber harvest in headwater areas.

Increases in streamflow

The 26.9 percent average annual increase in streamflow in Needle Branch following logging supports previous evidence that clearcut logging will generally result in increased streamflow (Reinhart et al. 1963; Rowe 1963; Rothacher 1965; Meehan et al. 1969; Berndt and Swank 1970). We have shown that this excess is generally expelled from the system during high winter flows. Principal months of excess streamflow in the study areas were December and January. Streamflow affects the timing of upstream migrations of adult salmonids, and we have shown the peak coho runs in this area also occur in December and January. One would anticipate that variations in streamflow at this time might affect the timing of runs of adult coho salmon. Au (1972) found this was the case, but the movement and numbers of fish depend more on the number of periods of streamflow increase than on the total volume in a given area. The timing of stream flow periods was unchanged, only the volume.

Logging and the gravel environment

The intragravel environment was significantly changed by logging activities. The entire zone was altered directly and indirectly by changes in physical components. Sediment in Deer Creek and Needle Branch increased significantly following road construction. Sediment entering the gravel (fines less than 3.327 mm) was slightly greater in post-logging years, but the lack of sufficient pre-logging samples reduces the power of comparison. There was, however, some indication of an increase in gravel fines in post-logging years because permeabilities in Needle Branch decreased after logging. Within the gravel itself, there was also a distinct drop in winter dissolved oxygen after logging on Needle Branch. As a result of intragravel changes, developing eggs in the gravel after logging were exposed to reductions in intragravel dissolved oxygen concentrations, decreases in intragravel water velocity, and, apparently, some alteration in the gravel composition.

Despite these changes, we cannot statistically detect differences (from field data) in pre- and post-logging emergent survival percentages for coho salmon, sizes of emergent fry, or timing of incubation and emergence. The only indication that changes might occur comes from field correlation studies by Koski (1966) and laboratory studies by Phillips et al. (1975). In both cases, results indicate that increases in gravel fines will generally result in lower coho salmon emergence survival. Our field results imply that any increases in gravel fines were not sufficient to decrease the overall emergent survival of coho salmon.

Changes in surface dissolved oxygen

We have shown that surface dissolved oxygen levels were significantly reduced in Needle Branch during summer 1966, the time of logging. The increased water temperature in Needle Branch, by itself, partly decreased the oxygen solubility of the water. The primary cause of this decrease in surface dissolved oxygen was the logging debris remaining in the stream during summer 1966.

There were natural mortalities in Needle Branch in these critical dissolved oxygen periods. This was further demonstrated by live-box experiments with juvenile coho salmon. Coho died in less than 40 minutes (Figure 19), due directly to lethal levels of dissolved oxygen in many areas of the stream. Hall and Lantz (1969) showed surface dissolved oxygen levels in Needle Branch subsequently increased due to debris clearance. Levels returned to normal after winter freshets cleared the stream of excess logging debris, and acted as instruments of oxygen exchange and replenishment. However, numbers of smolts were not significantly changed the following year. We cannot say how much mortality in fishes was due to dissolved oxygen, and how much was natural.

Changes in fish populations

All fish species in Needle Branch were affected in some manner. For coho salmon, the results were short-term. Those juveniles in the stream at the time of logging were apparently stressed by the rise in water temperatures and the decline in surface dissolved oxygen concentrations. They were smaller in size than juveniles in previous or subsequent years. When these fish returned as adults, they were still smaller in size, indicating this initial freshwater growth component was not compensated by saltwater growth. In addition, downstream migration patterns for juvenile coho were altered for several years after the 1967 season (the time of maximum water temperatures).

FIGURE 3.
Downed timber on the lower portion of Needle Branch watershed, July 1966. Photo at approximately stream marker 244 m (800 ft), looking downstream.

FIGURE 4.
Needle Branch watershed at approximately 610 m (2000 ft), showing cut timber on west side, July 1966.

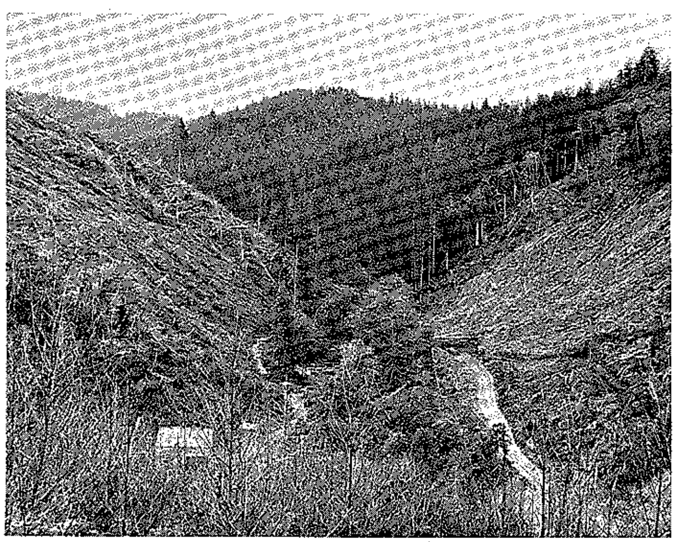


FIGURE 5.
Cutting on lower end of Deer Creek watershed, July 1966. The fish trap is located in the center of the photo.

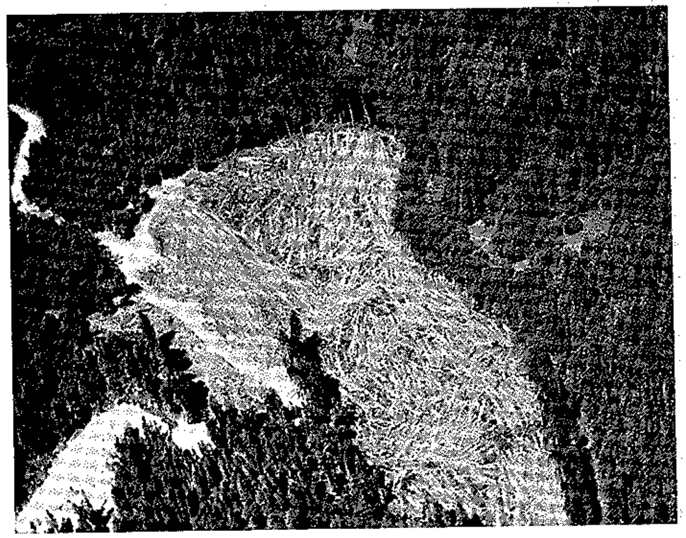


FIGURE 6.
A clearcut block on Deer Creek, with the buffer strip protecting the stream shown along the right side of the clearcut.

FIGURE 7.
Downed timber, slash, and debris in Needle Branch after felling.

FIGURE 8.
Logging debris in Needle Branch helped reduce flow and create critically low levels of dissolved oxygen.

FIGURE 9.
Debris was hand cleared from Needle Branch during August 1966.

FIGURE 10. Buffer Strip along Deer Creek.

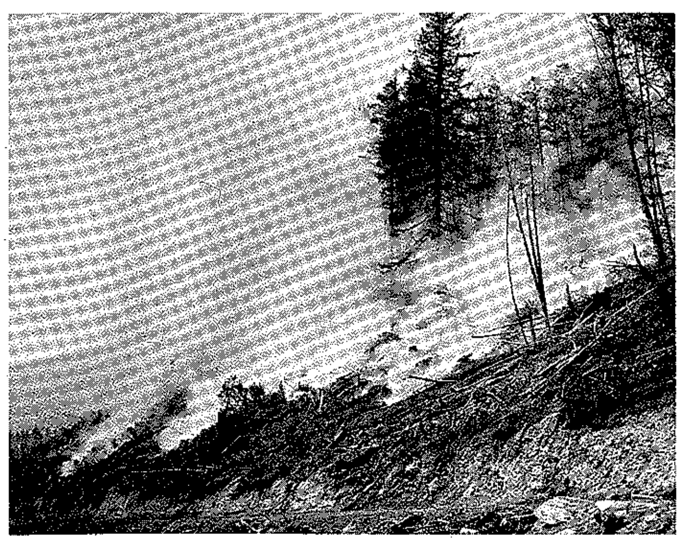


FIGURE 11. Slash burning in the Deer Creek watershed.

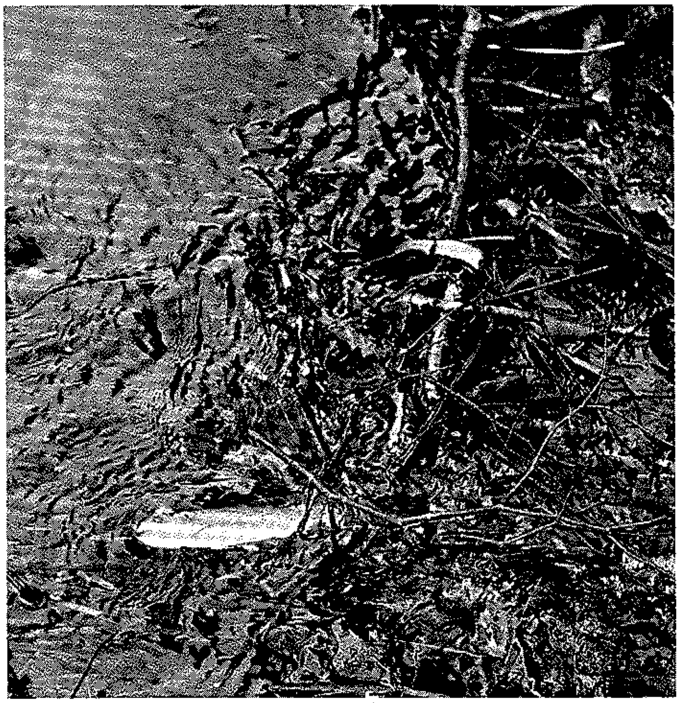


FIGURE 12.
Dead cutthroat trout and juvenile coho salmon in Needle Branch. These fish were killed during 1966 from flash heating by slash fires.

FIGURE 13. Erosion and siltation along one of the skid roads by lower Needle Branch, during a freshet in January 1967.

FIGURE 14.
The lower and central portion of Needle Branch watershed following clearcutting and slash burning.

FIGURE 15. The upper falls of Needle Branch following cutting and burning, February 1967.

FIGURE 16. Looking upstream from the 427 m (1400 ft) marker on Needle Branch, April 1967.

FIGURE 17.
Alder returned to the banks of Needle Branch, attaining a height of 4.6 m (15 ft) in some sections by 1969 (shown here). However, it was not until 1973 that riparian vegetation was sufficient to reduce water temperatures to near pre-logging levels.

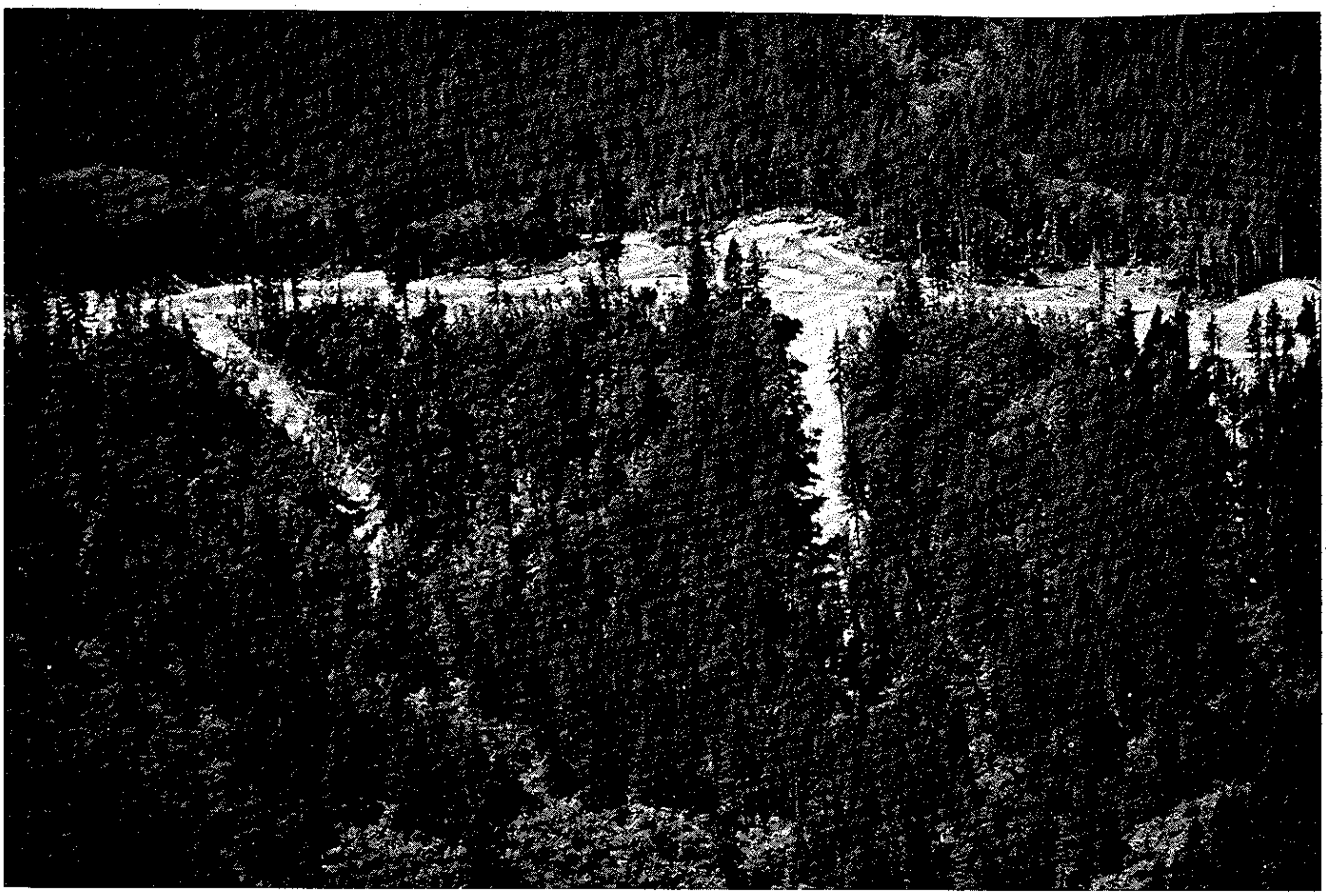


FIGURE 18. Road slumps and slides from a logging road in the Deer Creek watershed.

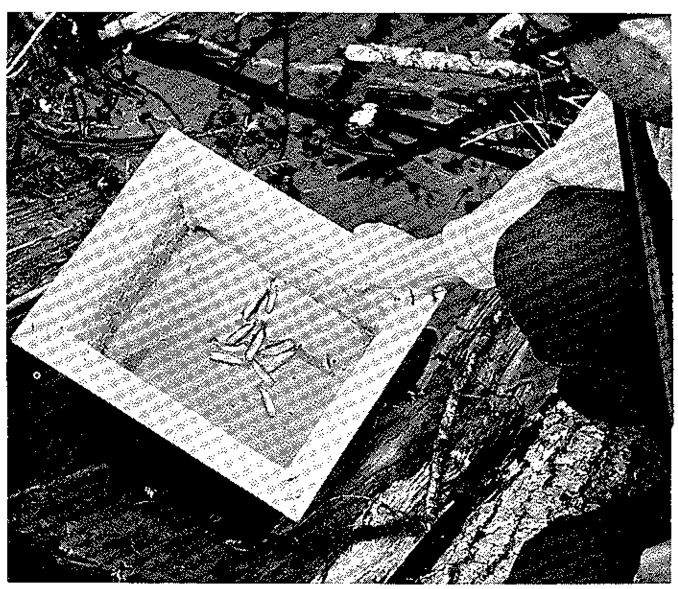


FIGURE 19.
Juvenile coho salmon in a live box in Needle Branch, July 1966. Fish were killed by critically low surface dissolved oxygen levels in the stream during the summer of 1966.

Numbers of lampreys were reduced in post-logging years, but the biological or ecological significance of this change is unknown. The Needle Branch reticulate sculpin population, however, was definitely altered by logging. The population was directly affected by cutting, debris in streams, and slash burning. Krohn (1968) theorized eggs of reticulate sculpin hatched during periods of unfavorable environmental conditions. As a result, the two youngest year classes largely disappeared during the summer of logging, 1966. The population remained altered for an unknown number of years following logging. Unfortunately, Krohn ended his study shortly into the post-logging period. It is believed, on the basis of trap records, that sculpin numbers were returning to pre-logging levels by 1973.

The cutthroat trout population was significantly altered in Needle Branch, and the effects were long-term. We believe the initial decline in the population was due to environmental shock: a rapid increase in summer water temperatures, with critically high water temperatures during many days of the first few years, and critical levels of intragravel and surface dissolved oxygen. We know the cutthroat were responding to these thermal changes because downstream migrations of cutthroat (as well as coho) occurred earlier in the two years following temperature maxima; probably a reflection of migration triggered by water temperatures. These preferred water temperatures, or increases in water temperatures, occurred earlier during this period.

Water temperatures began to return to normal values over the post-logging years, and the low dissolved oxygen levels returned to normal, but the cutthroat trout population in Needle Branch remained depressed. Other factors held the population in check. One of two things may have occurred after logging: (1) a combination of changes in the biological and physical components of the stream may be working together to keep cutthroat trout populations depressed, or (2) habitat suitable for cutthroat trout may be more confined in post-logging years, and the carrying capacity of the stream for cutthroat may be lower. We have some inferences that both changes may have occurred, but we have no definitive evidence for either. After debris clearance in Needle Branch, cover for cutthroat trout and other fishes was reduced, but how much this affected cutthroat populations, even in later years when riparian vegetation returned, is unknown. We theorize that the sudden environmental changes coupled with a sudden reduction in suitable cover combined to alter cutthroat populations in the early post-logging years.

RECOMMENDATIONS

BUFFER STRIPS

The preservation of buffer strips is essential for the prevention of direct physical changes and indirect biological changes in the stream environment. We have shown in this study that buffer strips along Deer Creek prevented significant alterations of the physical and biological components that occurred in the stream without buffer strips, Needle Branch.

Buffer strips were shown in this study to be important in temperature control, reduction of excess gravel scouring, and disruption of stream habitat. The most significant feature of buffer strips is their function as "policemen" against logging near streambanks. Without their presence, it would be much easier for damage, intentional or otherwise, to occur. Buffer strips need not be a specified width, nor do they need to include commercial timber. This timber can be removed from the buffer strip zone if felling and yarding is away from the stream. Brazier and Brown (1973) found 90 percent of the maximum shading ability of buffer strips (including those along Deer Creek) was found within a buffer width of 55 feet 20m (from each bank). From a biological point of view, the important criteria in the design of a buffer strip are the amounts of solar radiation reaching the stream and the maintenance of stream and streambank integrity.

ROAD DESIGN, CONSTRUCTION, AND MAINTENANCE

Roads should be designed and constructed so as to minimize their function as a source of excess sediment and mass transport of material in subsequent years. We have shown in this study that sedimentation increased in Deer Creek and Needle Branch, and that a principal source of this sediment increase (particularly in Deer Creek) was logging roads. Brown and Krygier (1971) documented the excess sediment loads from roads in the Deer Creek and Needle Branch watersheds.

Where possible, roads should be designed to utilize natural benches and saddles. Roads and sidecast material should be as far from the stream as possible, to minimize sedimentation. Whenever possible, unstable soil areas should be avoided. Roads constructed in these areas might continue to be a source of sedimentation in later years. At stream crossings, it is important to make sure the stream will not be blocked, either in construction or after the road is abandoned. Culverts at these crossings must take into account the fish species present, and their ability to move into and through culverts. Many states are now issuing guidelines for use of culverts, and these specifications should be followed.

We have shown in this study that maximum streamflow, before and after cutting, occurs in winter months, particularly during freshets. Avoid winter road building, as the chances of sediment entering streams are maximized at this time. Koski (1966) and Phillips et al. (1975) have shown that excess sediment fines in gravel will reduce emergent survival for coho salmon and steelhead trout. An increase in sediment from winter road building can only have detrimental effects on eggs which are developing in the gravel at that time.

FELLING

Whenever possible, no felling should occur into or across the stream itself, or on to the immediate bank. We have photographic evidence of Douglas-fir felled atop known coho salmon redds, with developing eggs in the gravel. Felling into streams results in excess slash and debris remaining in the stream, and the eventual yarding of downed timber from the stream. In addition, felling into streams has been shown in related studies (Moring and Lantz 1974) to partially destroy the protective functions of a buffer strip or any riparian vegetation.

YARDING

No logs should be yarded across or through streams. Such activity increases debris in streams, destroys riparian vegetation, scours gravel, breaks down stream integrity, disrupts or excavates developing salmonid eggs in the gravel and increases sedimentation to downstream areas. Whenever possible, downed logs should be yarded away from the stream by uphill high-lead yarding or use of ballons or helicopters. It is important to realize that any yarding in the proximity of a small stream can destroy vegetation, expose soil, and become a continuing source of sediment during winter freshets. The stream should never be used as a highway for yarding logs. From a biological viewpoint, the long-term damage can be extensive.

DEBRIS CLEARANCE AND THE VALUE OF COVER

Excess logging debris should be removed from a stream as soon as possible after felling; even if a buffer strip is present and debris is not extensive. We have documented in this study that debris remaining in Needle Branch after clearcutting created critically low surface and intragravel dissolved oxygen concentrations. Fish died because of lack of sufficient dissolved oxygen. It was shown quite dramatically that once the debris was cleared from Needle Branch, the surface dissolved oxygen levels returned to normal. Intragravel dissolved oxygen was much slower to respond to debris clearance and winter freshets, so debris should definitely not remain in the stream over winter, when salmonid eggs in the gravel rely on adequate levels of dissolved oxygen for growth and development.

Excess debris in the stream from logging operations creates an artificial situation. We have shown that this is detrimental. However, clearance of all debris creates another artificial situation, one where some natural cover is removed. Lewis (1969) found that cover and current velocity were the two most important factors influencing rainbow and brown trout populations in streams. Cederholm et al. (1975) have indicated that indiscriminate debris removal can result in changes in pool-riffle ratios and excessive stream erosion in winter freshets. Apparently, the presence of natural amounts of debris is useful in preserving stream stability. Therefore, during debris clearance, some material should be left in the stream for these cover and stream stability functions.

CONSULTATION WITH AGENCIES CONCERNED WITH FISH RESOURCES

It should become a matter of policy, when headwater streams may be affected in a potential cutting, to consult with the State fisheries agency and/or their district biologists. The potential damage to stream habitat and fish populations has been well documented in Parts I and II of the Alsea Watershed Study report. When these important spawning and rearing areas may be exposed to any type of logging operations, the State fisheries agency, with management responsibilities, should have input into logging plans.

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Many individuals connected with the Alsea Watershed Study have already been identified in Parts I and II. I am particularly grateful to Messrs. Richard Lantz and Bruce Pohl for background assistance. Thanks are also due the following for reviewing the manuscript: Dr. Harry Wagner and Mr. Homer Campbell of the Oregon Department of Fish and Wildlife, Research Section, and Dr. James Hall of Oregon State University.

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